THE ROLE OF BIOMASS BASED COGENERATION: CASE OF AN ITALIAN PROVINCE

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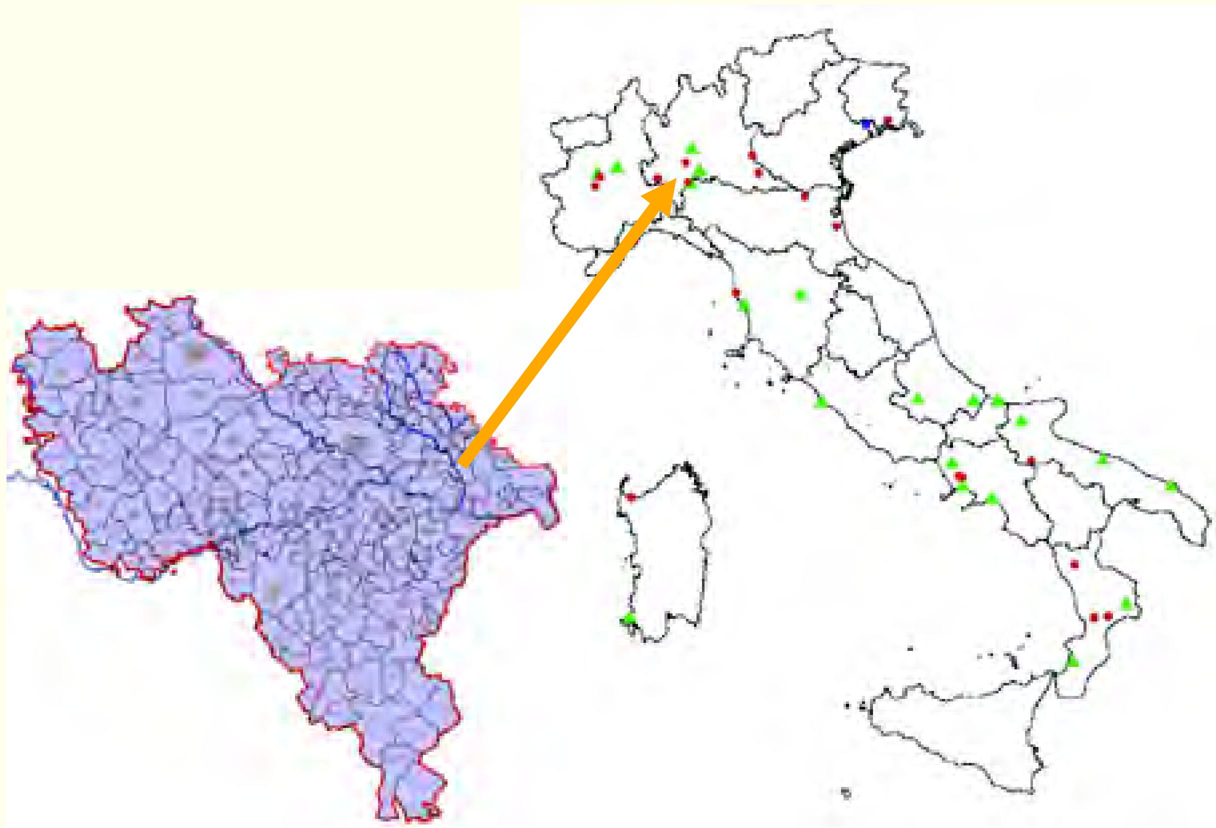
SCOPE

* Research work: energy modeling of the Province of Pavia.

The aim is to analyze and compare different energy developement scenarios to provide a strategic assessment of measures for the local energy planners, through an optimization model.

Province of Pavia (PP) – Northern Italy

Area 3 000 km^2
Population : 512.000
Municipalities : 190



SCOPE

Final Energy Consumption of the Province of Pavia in 2003 (ktoe)							
	agric.	industry	civil	transport	electricity production	Tot	%
electricity	12.3	277.2	260.1	13.1	0	**562.7**	23%
natural gas	0	690.3	360.3	1.8	85	**1137.4**	47%
gasoline	2	0	0	133.9	0	**135.9**	6%
gasoil	23.3	4.5	16.4	160.4	0	**204.6**	8%
GLP	0	0	11.5	5.8	0	**17.3**	1%
oil	0	133.9	4.9	0.2	0	**139**	6%
petcoke	0	104	0	0	0	**104**	4%
Total	**37.6**	**1343.8**	**658.1**	**315.4**	**85**	**2439.9**	100%
%	2%	55%	27%	13%	3%		

SCOPE

Main drivers of the study

1 - the role of the distributed vs. the centralized and/or imported generation;

2 - impact of local and imported biomass utilization on energy planning;

3 - focus on the non industrial sector;

4 - reduction in the residential electricity consumptions;

Main questions

→ how many decentralized biomass power plants can be authorized without jeopardizing (or minimizing) the use of land, currently addressed to food production?

→ How sustainable is the use of imported biomass from Far East countries in a local-limited context?

METHODOLOGY

Methodology applied is ALEP (Advanced Local Energy Planning) developed by IEA (International Energy Agency) whose aim is to develop consistent local energy plans.

The used tool is Standard MarkAl, a dynamic energy model generator based on linear programming, written in GAMS. (The minimized objective function is the discounted sum, over the considered time horizon, of the net total costs, made up of investments, O&M costs…).

Results are focused on the impact of the **partial** achievement of two of the EU commitment for the year 2020:
(i) 20% share of electricity (**for non-industrial use**) from renewables ;
(ii) 20% reduction in the residential electricity consumptions.

PPMM ***(Province of Pavia MarkAl Model)***

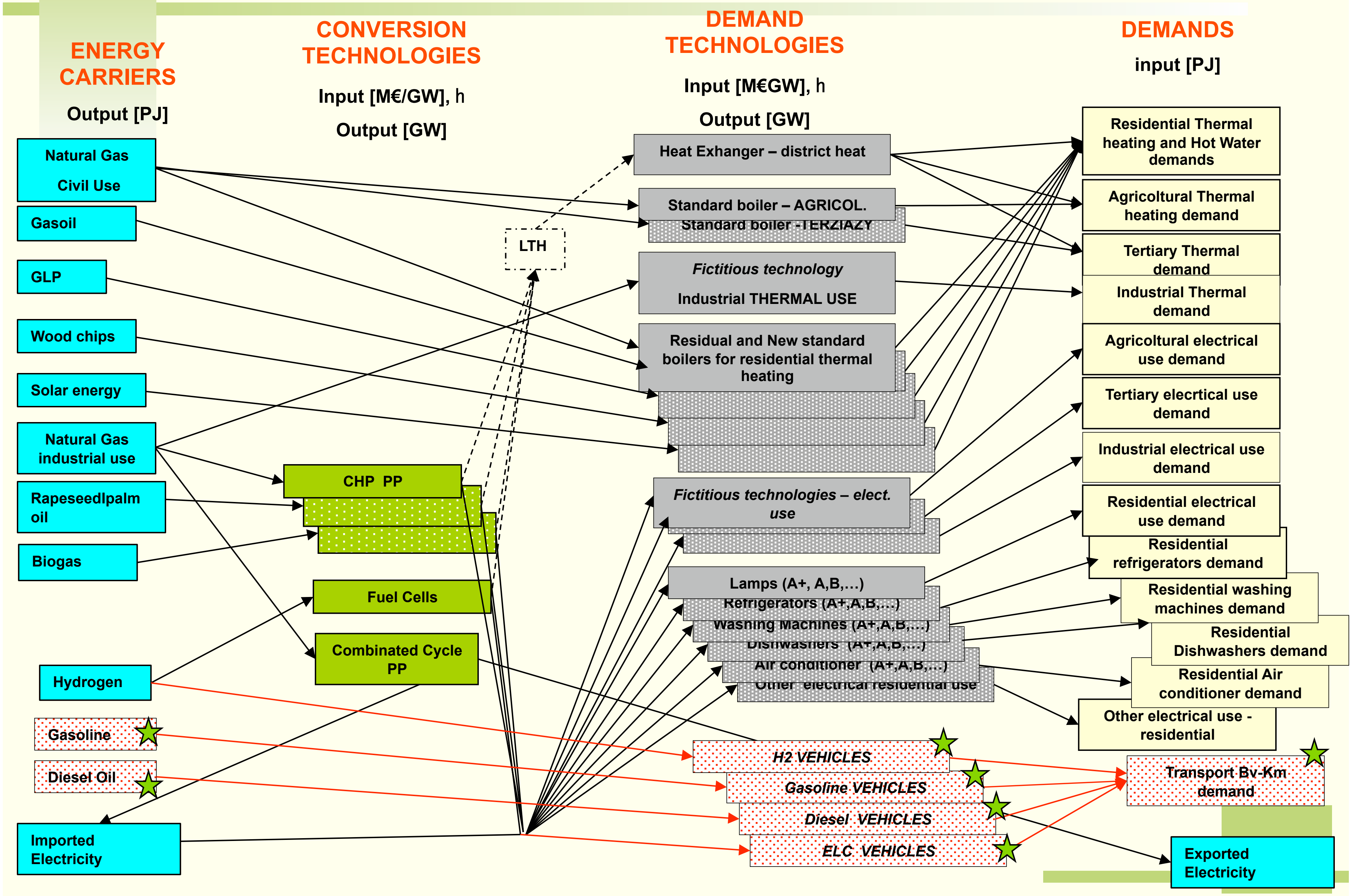
PPMM includes the whole energy system and the main features are:

(i) detailed modeling of the residential sector (final energy demands and technologies);

(ii) detailed modeling of the electricity supply sector;

(iii) evaluation of the biomass availability in PP and potential for energy purpose (diversification and security of supply).

PPMM – Reference Energy System



PPMM – residential heating demand assessment

Analysing data from the ISTAT 2001 census database and CTI (Italian Thermotechnical Committee) documents:

S = area of residential buildings/apartments in province of Pavia *(ISTAT)*

l_i = Building stock share by period of construction (i) *(ISTAT)*

$a_{i,j}$ = Building stock share by period of construction (i) and features (j) *(CTI)*

Hypothesis

$b_{i,l}$ = Building stock share by vintage and features of the glasses (l)

i = 1,2,3,4

1 = before 1900 to 1945, **2** = 1946 – 1971, **3** = 1972 – 1981 , **4** = 1982 – 2001

6 dwelling categories

$D_{j,l}$ l=1,2,3 ; m=1,2

j = 1 (brickwork), 2 (concrete perforated bricks), 3 (cavity walls)

l = 1 (double glass), 2 (single glass).

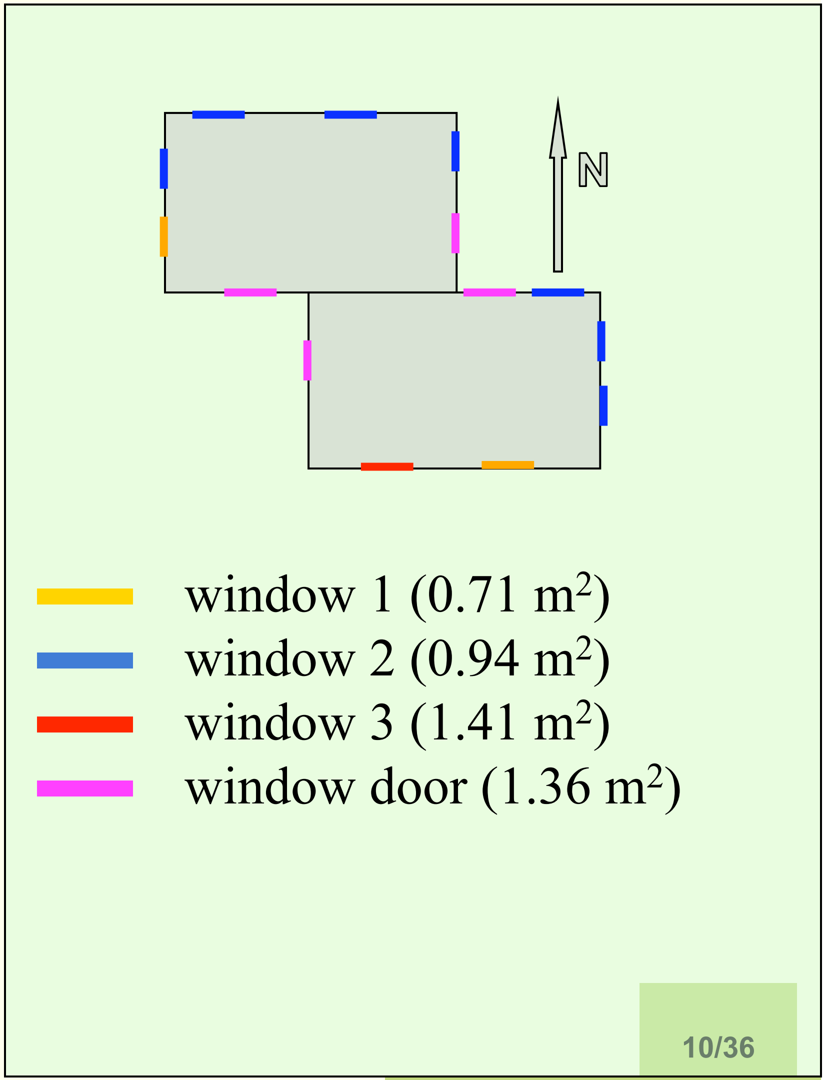
PPMM – *residential heating demand assessment*

The residential heating demand of a standard building for each category (j,l), has been calculated:

Standard building

- **3 floors**
- **6 apartments**

→single apartment surface = 90 m^2
→single apartment high (H) = 3 m
→single apartment glass surfaces
North 4.18 m^2
South 3.48 m^2
East 4.18 m^2
West 3.01m^2



- **Total building volume = 2160 m^3**
- **Total building height = 12 m**

PPMM – residential heating demand assessment

National technical standard UNI 7357

The seasonal residential heating demand ($Qh_{l,m}$), for the category j,l (meaning the amount of heat needed for the seasonal heating)

$$Qh_{j,l} = Qt_{j,l} + Qv - \eta \cdot Qg_l$$

$Fh_{j,l} = Qh_{j,l}/V$ (kWh/m^3) ← Specific residential heating dmd

-**$Qt_{j,l}$** is the amount of energy lost through the building surfaces (walls, windows, roofs and basements) and depends on the transmittance of the walls (**k_j**), of the glasses (**k_l**), of the roof (k1) and of the basement (k2). For practical reasons we took k1 and k2 constant for each (lm) category.

-**Qv** is the amount of energy lost by venting;

-**Qg_l** are the heat gains (like indoor equipment, sun).

-**h** is the heat gains utilization factor.

Vintage (k)	Building stock share by vintage (l_k)	share of dwellings by features in period k $(a_{k,l})$			share of double glasses in period k $(b_{k,m})$	
		brickwork $(a_{k,1})$	concrete perforated bricks $(a_{k,2})$	cavity walls $(a_{k,3})$	double glasses $(b_{k,1})$	single glasses $(b_{k,2})$
before 1900 to 1945	29%	100%	-	-	20%	80%
1946 -1971	49%	20%	10%	70%	20%	80%
1972 - 1981	13%	10%	30%	60%	20%	80%
1982 - 2001	10%	5%	30%	65%	20%	80%
heat demand calculated for each category (kWh/ m³) **(Fh)**		$Fh_{1,1}$ 26.7	$Fh_{2,1}$ 33.9	$Fh_{3,1}$ 30.6		
		$Fh_{1,2}$ 29.2	$Fh_{2,2}$ 36.4	$Fh_{3,2}$ 33.1		

PPMM – residential heating demand assessment

The residential heating demand for the Province of Pavia

$$Qh_{tot} = S \cdot \sum_{i} H_{i} \left[\sum_{j=1}^{3} \left(\sum_{l=1}^{2} \Phi_{j,l} \cdot \alpha_{i,j} \cdot \beta_{i,l} \right) \right]$$

Projection assumptions (2003 – 2030)

- *Rate of renovated buildings → 1.5%/y ;*
- *Rate of new buildings → 0.6%/y ;*
- *Energy performances of new and renovated dwellings according with Italian Law 311/06*

PPMM – residential heating demand assessment

Rating system and distribution of the buildings depending upon their heating demand in 2001

	Rating system range $E_h = Q_{hj,l}/m^2$ (kWh/m^2)	Percentage distribution of buildings in the year 2001
A	Eh ≤ 30	0
B	30 < Eh ≤ 50	0
C	50 < Eh ≤ 70	0
D	70 < Eh ≤ 90	17%
E	90 < Eh ≤ 110	76%
F	110 < Eh ≤ 130	7%
G	130 < Eh ≤ 160	0

PPMM – residential thermal sector

54 demand technologies

Standard:

- gas boilers (standard B. + condensing B.)
- gasoil boilers
- GLP boilers
- district heating from fossil fueled CHP

Renewables

- wood chips boilers
- natural circulation solar collectors
- forced circulation solar collectors
- vacuum pipe collectors
- condensing boiler and solar-thermal combination
- district heating from renewable CHP

PPMM – residential electricity sector

Electricity demands assessment

6 categories has been considered:

- lighting dmd (Glm);
- refrigerators dmd (10^6 devices);
- washing machines dmd (10^6 devices);
- dishwashers dmd (10^6 devices);
- air conditioners dmd (10^6 devices);
- other end use technologies (TV etc…)

(10^6 devices).

PPMM – residential electricity sector

Electricity demands assessment

indexes and hypothesis used for the assessment of the residential electricity end use demands.

	Share of houses, with devices (2003) (ISTAT, ENEA)	3 years increase factor (%)
refrigerators	100%	4%
washing machines	100%	0.5%
dishwasher	32%	4%
air conditioner	15%	1.5%

Lighting dmd → 200 lux (lm/m^2)
Rate of new buildings → 0.6%/y

PPMM – residential electricity sector

28 demand technologies

	refrigerators		washing machines		dishwashers		air conditioners	
eff. ranking index	consumption [kWh/a]	INVCOST [€/device]	consumption [kWh/a]	INVCOST [€/device]	consumption [kWh/a]	INVCOST [€/device]	consumption [kWh/a]	INVCOST [€/device]
A++	160	800						
A+	250	500	190	500			350	800
A	304	350	220	450	250	550	500	550
B	406	280	275	400	300	500	600	480
C	516	220	325	350	330	450	650	420
D					380	400		
Other (<D)	600	160	475	200	440	350	750	300

	efficiency [lm/W]	Investment cost [M€/(Glm/y)]
Bulb lamp	12	1.8
Halogen lamp	15	2.6
Linear fluorescent lamp	65	6.6
Compact fluorescent lamp	60	9.6
LED	250	38.9

PPMM – electricity supply sector

6 conversion technologies: small-sized CHP plants (<1MWe):

Tech.	Fuel	INVCOST [M€/GW]	Fixed O&M Cost [M€/GW]	ENVACT CO_2 emission factor [kt/PJout]	Efficiency (Electrical+ Heat recovery)	REH - Electricity over Heat Recovery rate
Reciprocating engines	Natural Gas	700	21	159	85%	0.7
	Biogas	750	22.5	-	85%	0.7
	Rapeseed oil	1000	30	0.3 (*)	80%	0.78
	Palm oil	1000	30	4.7	80%	0.78
Gas Turbine	Natural gas	500	15	279	60%	0.5
	Biogas	550	16.5	-	60%	0.5

(*) to be considered only for imported rapeseed oil.

PPMM – biofuels availability assessment

Considered Biofuels:

***Local:* rapeseed oil, biogas**

***Imported:* rapeseed oil (neighboring area), palm tree oil (extraeuropean)**

Local availability:

- rapeseed production assessment → 0.18 PJ/y (4800 t/y) inferred considering 5000 ha of available land (land that cannot be used for agricultural purpose);

- biogas production assessment → 0.43 PJ/y (12 MS^3/y) inferred considering the anaerobic digestion of local farm animal waste.

Exogenous availability:

- rapeseed import assessment → 0.36 PJ/y (9600 t/y)

- No bounds on palm tree oil import

MODEL ASSUMPTIONS

Rate of renovated buildings→ 1.5%/y ;

Rate of new buildings → 0.6%/y ;

Discount rate → 4%/y ;

Time horizon → from 2003 to 2030, being divided into 10 periods (3 year each);

Emission factor due to transportation of Rapeseed oil and Palm tree Oil import;

Calibration done by using data on the efficiency of the provincial inspection database on residential boilers (representing 15-20% of the whole provincial stock);

SCENARIO ASSUMPTIONS

Two scenarios have been compared in terms of costs and performances: BASE vs. S2T20

BASE → reference scenario

Two different kinds of subsidies (according to the italian law):

(i) the green certificates (GC) for palm-tree oil technologies (115 €$_{2009}$/MWhe);

(ii) the traceable chain supply biomass (representing a sort of import from neighboring area) (SC), affecting both biogas and rapeseed oil use (280 €$_{2009}$/MWhe).

SCENARIO ASSUMPTIONS

S2T20 → alternative scenario

1) The target is to deliver a share of 20% electricity **(non industrial consumption)** from renewables.

In BASE scenario renewable share in electricity production in 2020 is 7% → endogenous resources are not enough;

one additional subsidy→ to let palm-oil technologies enter the market.

Palm oil → 15.5 M€/PJ (160 €/MWhe)

2) 20% reduction in the residential electricity consumptions → hypothesis on the household appliances market.

RESULTS

CHP electricity production / Non Industrial ELECTRICITY Consumption			
		2020	**2030**
BASE	fossil-fuelled electricity	62.46%	54.58%
BASE	electricity from renewables	7.73%	6.70%
S2T20	fossil-fuelled electricity	58.59%	24.96%
S2T20	electricity from renewables	20.54%	58.83%

Local endogenous resources → 3%

the model invests on CHP systems for a high share of consumptions.

Is it feasible?

Next step will be to found an upper bound for CHP installed capacity.

RESULTS

CHP thermal production / Non Industrial THERMAL Consumption			
		2020	**2030**
BASE	thermal demand from fossil fuels	11.24%	10.45%
BASE	thermal demand from renewable	0.95%	0.88%
BASE	thermal demand from ALL renewable	6.18%	5.75%

S2T20	thermal demand from fossil fuels	9.90%	4.49%
S2T20	thermal demand from renewable	2.29%	6.83%
S2T20	thermal demand from ALL renewable	7.52%	11.70%

The 20% share of renewable on heating consumption is far to be reached by 2020.

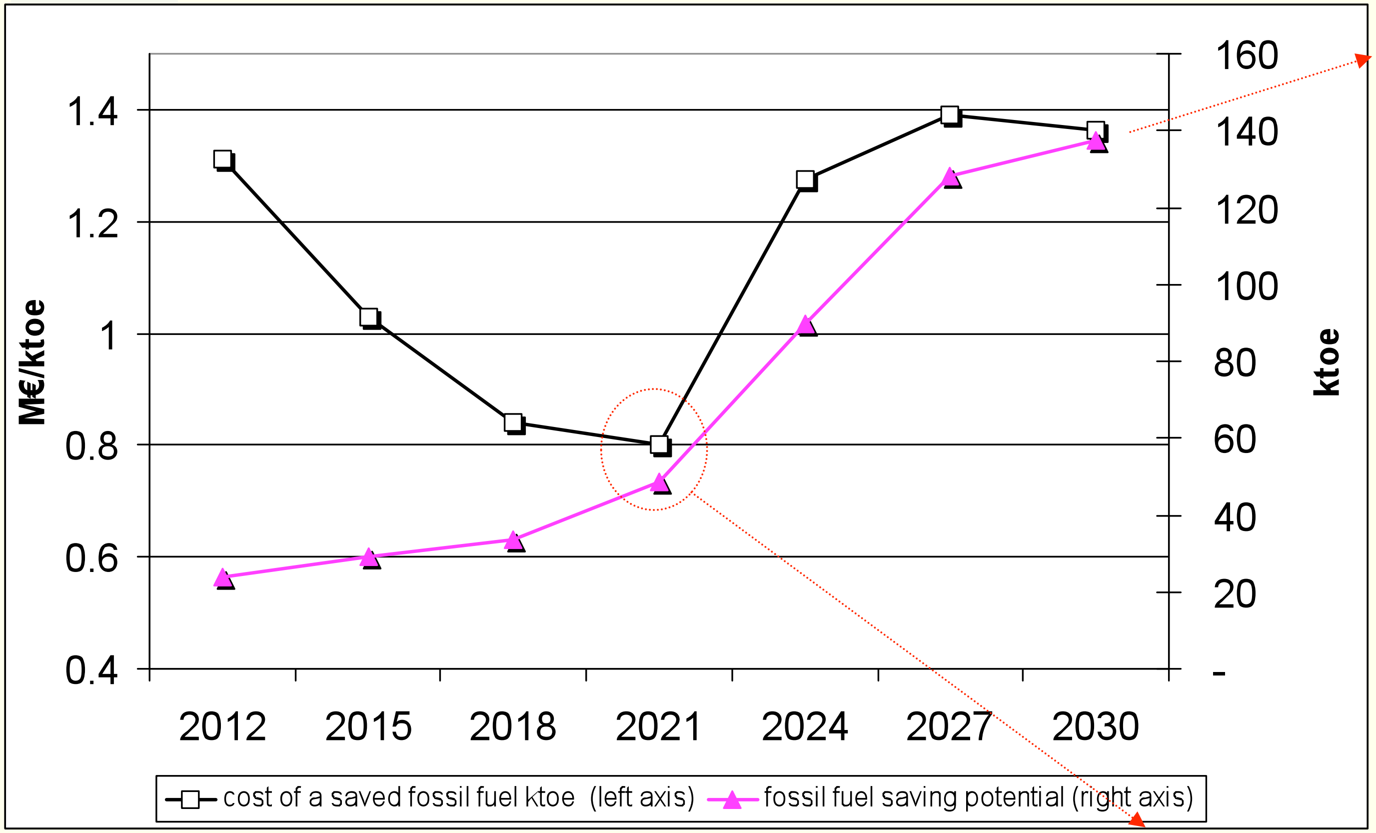
Different solutions must be investigated .

RESULTS

Scenarios Comparison – significant indexes			
	2010	**2020**	**2030**
Fossil fuel saving potential Δ Fossil Fuel Consumption (FFC) - (ktoe) $[FFC^{(BASE)} - FFC^{(2T20)}]$	24	49	137
CO2 saving potential Δ Total CO_2 emission (E) - (kt) $[E^{(BASE)} - E^{(2T20)}]$	122	207	741
$[E^{(BASE)} - E^{(2T20)}] / E^{(BASE)}$	4%	6%	20%
	2010	**2020**	**2030**
Cost of a saved ktoe [$M€_{2003}$/ktoe]	1.31	0.80	1.36
Cost of a saved kt of CO_2 [$M€_{2003}$/kt]	0.26	0.19	0.25

RESULTS

Cost of a saved fossil fuel ktoe VS. [FFC$^{(BASE)}$ - FFC$^{(2T20)}$]



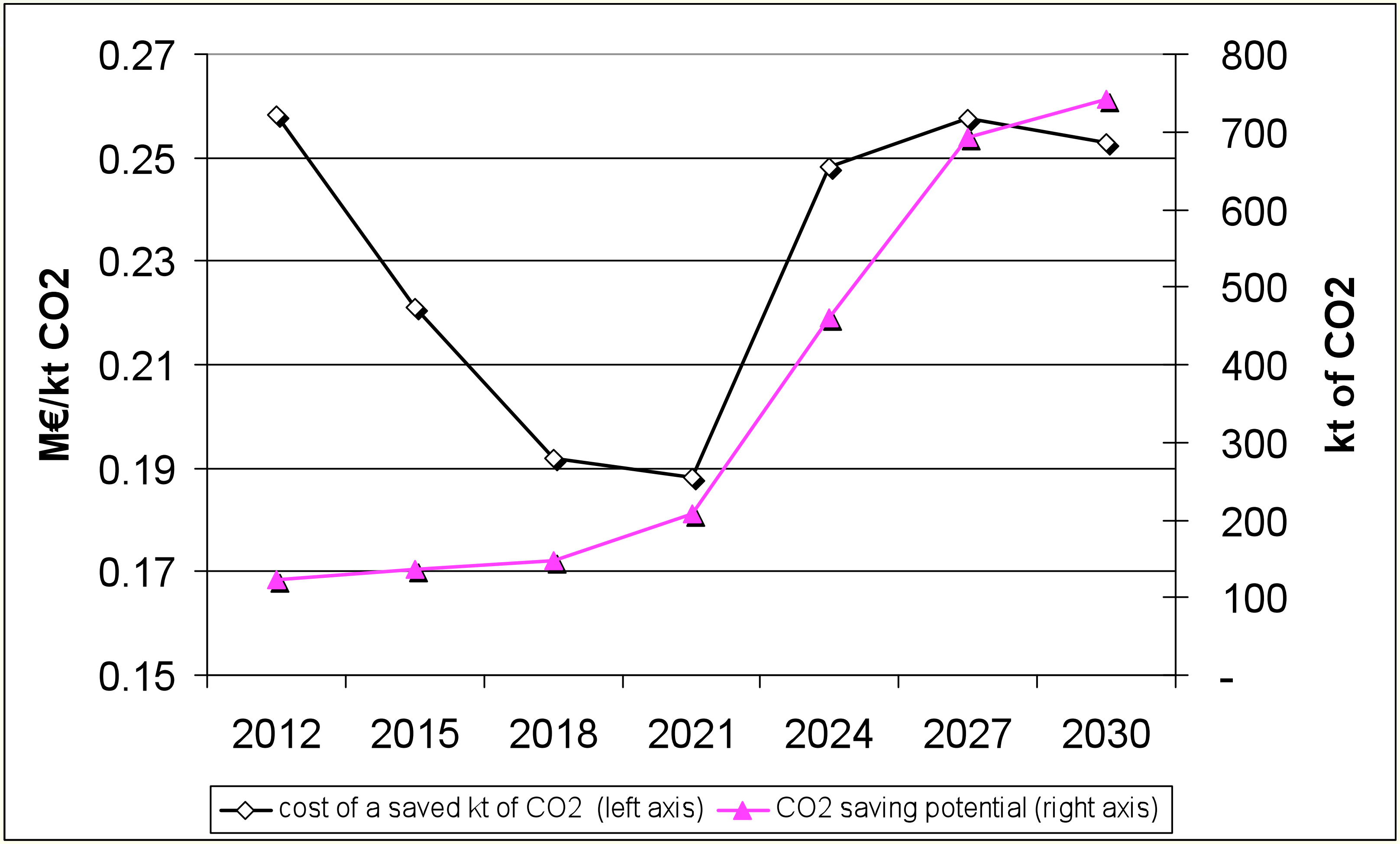
59% of renewable production/ consumptions.

Different solutions must be investigated and compared in order to contain the liquid biomass import and utilization.

The 2020 configuration seems to be one with the best investment-effectiveness-rate (?) these conclusions will be better investigated.

RESULTS

Cost of a saved kt of CO_2 VS. [$E^{(BASE)}$ - $E^{(2T20)}$]



RESULTS

In a previous study [1] (*) the impact of improvements in the buildings efficiency has been evaluated.

SCA SCENARIO →

The 70% of the new building fall in the A-rated consumption range

SCA significant indexes			
	2010	**2020**	**2030**
SCA Fossil fuel saving potential [ktoe]	2	4	6
SCA CO2 saving potential [kt]	10	18	26
Cost of a saved ktoe [M€$_{2003}$/ktoe]	5.04	2.04	1.42
Cost of a kt of CO_2 [M€$_{2003}$/kt]	1.21	0.5	0.36

Fossil and CO2 saving potential are much lower than in S2T20 – (4 Vs.49 ktoe and 18 Vs 207 in 2020).

Costs are higher.

(*) Presented at IEW 2008 and at ECOS 2008

RESULTS

SH2B → alternative scenario

The target is to deliver a share of 20% electricity **(non industrial consumption)** from hydrogen fuel cells.

Hypothesis → H_2 from a renewable mix (p.e solid biomass gasification)

Tech.	**Fuel**	**INVCOST [M€/GW]**	**Fixed O&M Cost [M€/GW]**	**ENVACT** CO_2 emission factor **[kt/PJout]**	**Efficiency (electrical+ Heat recovery)**	**REH - Electricity over Heat Recovery rate**
Fuel Cells	Hydrogen	10000(**) pr = 0.9	300(**)	-	80%	2.2

technology learning features of MarkAl ha been used

(**) to be considered for 2006, the starting year of the learning curve

RESULTS

SH2B analysis → preliminary results

a subsidy of 0.82 €/kWh is needed in order to make the fuel cell competitive

SH2B significant indexes		
	2020	**2030**
SH2B Fossil fuel saving potential [ktoe]	167	621
SH2B CO2 saving potential [kt]	86	708
Cost of a saved ktoe [$M€_{2003}$/ktoe]	8.79	10.53
Cost of a kt of CO_2 [$M€_{2003}$/kt]	1.93	0.88

Fossil fuel saving potential is higher than in S2T20 – (167 Vs.49 ktoe).

CO_2 saving potential is lower (86 Vs 207 ktoe in 2020).

Costs are higher.

The idea is to evaluate these different options using the multiobjective linear programming technique (MOLP)

RESULTS

	Residential Electrical Sub System annualized Cost (**RESSC**) [€/household]		
	2010	**2020**	**2030**
BASE	416	494	521
S2T20	414	502	521

Cumulated value of the White Certificates (100€/saved toe for 5 years) from 2003 to 2020 → 15M€ (0.78M€/y)

CONCLUSIONS

biomass-based distributed generation can play a key role in energy saving but a careful managing of the local resources is necessary for the sustainable development of a local territory,

mainly big-sized power plants can benefit from Green Certificates, being characterized by lower investment cost (M€/MW), higher electrical efficiency and higher CF value, despite of having a lower total efficiency (no heat recovery is considered for such plants),

the most efficient technologies (electricity use in the residential sector) are still competitive and a low subsidy is needed in order to make them enter the market,

Green Certificates and White Certificates further investments that maximize the investor benefits to the detriment of the optimal utilization of resources.

NEXT DEVELOPEMENTS 1/2

PP MarkAl model development

- Detailed modeling of the commercial sector;
- Detailed modeling of the transport sector;
- UE 20-20-20 achievement: economic/ technological conditions;

NEXT DEVELOPEMENTS 2/2

1. Sensitivity analysis – biofuels vs fossil fuels price;

2. PPMM analysis with stochastic-MarkAl

3. Using other tools/models in parallel with MarkAl
   (agent based, GIS, MOLP…)

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